Chas R. Nord

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 554

WIND-TUNNEL INVESTIGATION OF ORDINARY AND SPLIT FLAPS ON AIRFOILS OF DIFFERENT PROFILE

By CARL J. WENZINGER

1936

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)	---------	horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s² or 32.1740 ft./sec.²

m, Mass $= \frac{W}{g}$

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu.ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $= \frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_o, Profile drag, absolute coefficient $C_{D_o} = \frac{D_o}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s. the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of *c.p.* from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_o, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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By Carl J. Wenzinger

SUMMARY

The Clark Y, the N. A. C. A. 23012, and the N. A. C. A. 23021 airfoils equipped with full-span ordinary flaps and with full-span simple split flaps were tested in the N. A. C. A. 7- by 10-foot wind tunnel. The principal object of the tests was to determine the characteristics of the airfoils with ordinary flaps and, in addition, to determine the relative merits of the various airfoils when equipped with either ordinary flaps or with simple split flaps. The Clark Y airfoil was tested with 3 widths of ordinary flap, 10, 20, and 30 percent of the airfoil chord. The optimum width of the ordinary and the simple split flap based on the maximum lift attained with the Clark Y airfoil was then tested on each of the other two airfoils.

The optimum width of ordinary flap for maximum lift attainable was found to be the same as that of the split flap, 20 percent of the airfoil chord. The split flap produced somewhat greater increases in $C_{L_{max}}$ *on the airfoils tested than did the ordinary flap of the same width, but the L/D at maximum lift was practically the same for the two types of flap. Any gap between the airfoil and the leading edge of ordinary flaps had a very detrimental effect on the* $C_{L_{max}}$ *attainable. Based principally on factors affecting airplane performance, the relative order of merit of the airfoils tested with either ordinary or split flaps is N. A. C. A. 23012, Clark Y, and N. A. C. A. 23021. The hinge-moment coefficients (based on flap chord and area) of the full-span ordinary flaps were practically independent of flap chord; the actual hinge moments varied approximately as the square of the chord. In addition, the hinge-moment coefficients of the split flaps were practically the same as those of full-span ordinary flaps of corresponding widths.*

INTRODUCTION

Many experimental investigations have been made of various types of flap for increasing, in particular, the maximum lift of airplanes as an aid to improved performance. Among the devices already investigated in considerable detail by the N. A. C. A. are simple split flaps, split flaps of the Zap type, Fowler flaps, and external-airfoil flaps. Some uncorrelated data are also available from various sources on slotted flaps and on ordinary flaps. Because of the simplicity of ordinary flaps and the lack of correlated data on them as a lift-increasing device, it appeared desirable to make a more complete investigation of this type of flap.

Three basic airfoil sections were used in the present tests to obtain an estimate of the effect of airfoil section and thickness. In addition to the Clark Y, the N. A. C. A. 23012 airfoil was selected as being representative of the best airfoils at present available for use on conventional airplanes, and the N. A. C. A. 23021 airfoil was selected as a representative thick section. Three widths of ordinary flap were tested on the Clark Y airfoil, and one width on each of the other two airfoils. For purposes of comparison one simple split flap was also tested on the N. A. C. A. 23012 and 23021 airfoils, and data are included from previous tests of the Clark Y airfoil with a split flap. The aerodynamic characteristics of the airfoils with all the different flaps were measured and, in addition, hinge moments were obtained for the ordinary flaps on the Clark Y airfoil.

MODELS AND TESTS

Models.—Mahogany models of the Clark Y, the N. A. C. A. 23012, and the N. A. C. A. 23021 airfoil sections were tested. The span of each model was 60 inches and the chord 10 inches. The Clark Y airfoil with the 3 widths of ordinary flap tested (10, 20, and 30 percent of the wing chord) is shown in figure 1. These flaps are arranged to lock rigidly to the airfoil or to rotate freely about their respective hinge axes. The other two airfoils are shown with ordinary flaps in figure 2 and with split flaps in figure 3.

The ordinates of the airfoil sections are included with the charts of their aerodynamic characteristics in figures 4, 5, and 6. The size of flap that gave the highest value of the maximum lift coefficient for the Clark Y airfoil together with reasonable hinge moments (20-percent-chord flap) was used with the N. A. C. A. 23012 and the N. A. C. A. 23021 airfoils.

Tests.—The tests were made in the N. A. C. A. 7- by 10-foot wind tunnel which, together with associ-

ated apparatus and standard test procedure, is described in reference 1. The dynamic pressure was maintained constant at 16.37 pounds per square foot, which corresponds to an air speed of 80 miles per hour under standard sea-level conditions. The average Reynolds Number for the tests was 609,000, based on the air speed and on the 10-inch airfoil chord. Lift,

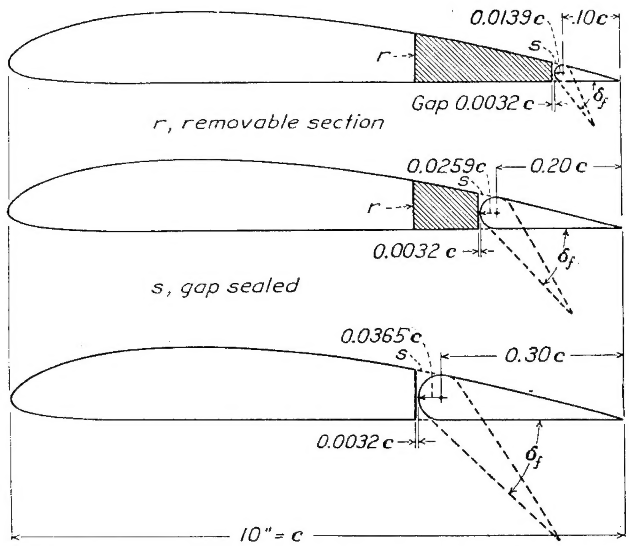

FIGURE 1.—Full-span ordinary flaps tested on the Clark Y airfoil.

drag, and pitching moments were measured for all flap arrangements with flap deflections from 0° to beyond those for maximum lift. The angle-of-attack range covered was from below zero lift to beyond the stall of the airfoil. Hinge moments were also measured for the three widths of ordinary flap on the Clark Y airfoil.

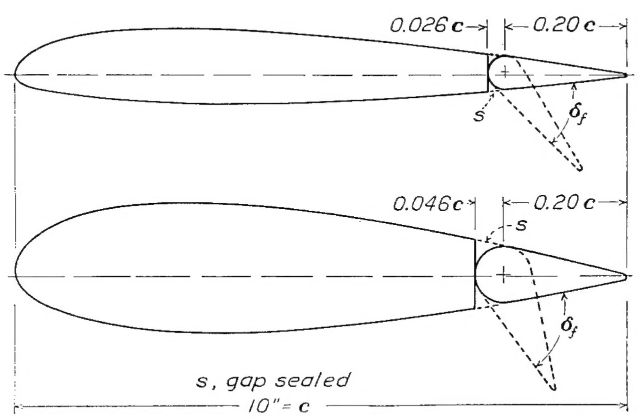

FIGURE 2.—Full-span ordinary flaps tested on the N. A. C. A. 23012 and N. A. C. A. 23021 airfoils.

These moments were obtained by the methods given in reference 2, which presents results of hinge-moment tests on split flaps of various chords.

RESULTS

Results of the investigation are given in standard nondimensional coefficient form for the following four coefficients:

$$C_L=\frac{\text{lift}}{qS}$$

$$C_D=\frac{\text{drag}}{qS}$$

$$C_{m_{c/4}}{}'=\frac{\text{pitching moment about quarter chord}}{qSc}$$

$$C_{h_f}=\frac{\text{flap hinge moment}}{qS_fc_f}$$

in which

S, airfoil area.
S_f, flap area.
c, airfoil chord.
c_f, flap chord.
q, dynamic pressure.

The data were corrected for the effects of the jet boundaries and for the tunnel static-pressure

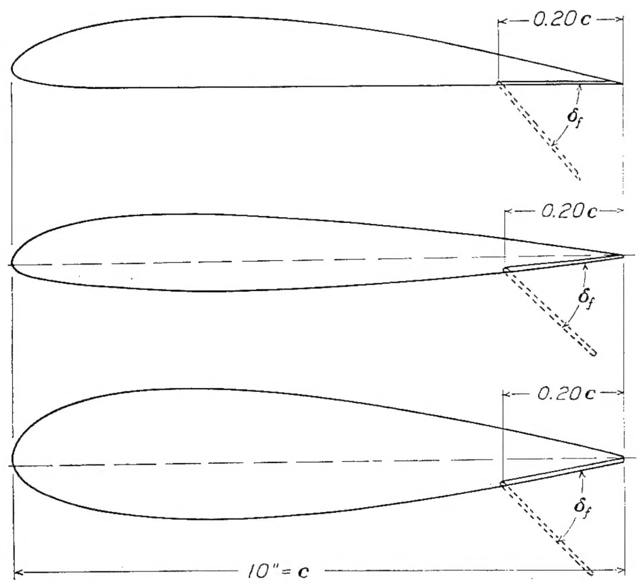

FIGURE 3.—Full-span split flaps tested on the Clark Y, the N. A. C. A. 23012, and the N. A. C. A. 23021 airfoils.

gradient. The standard jet-boundary corrections, $\Delta\alpha=\delta\frac{S}{C}C_L\times 57.3$, in degrees, and $\Delta C_D=\delta\frac{S}{C}C_L^2$, where C is the jet cross-sectional area, were used. The value of factor $\delta=-0.165$ was taken as being most nearly representative of the boundary effect in the 7- by 10-foot wind tunnel. (See reference 3.) The longitudinal static-pressure gradient in the 7- by 10-foot wind tunnel produces an additional downstream force on the model. This force corresponds to a value of $\Delta C_D=0.0015$ for rectangular airfoils of thickness equal to 12 percent of the chord and $\Delta C_D=0.0029$ for an airfoil having a thickness of 21 percent of the chord. These values were obtained in accordance with methods given in reference 4.

DISCUSSION

PLAIN AIRFOILS

Complete aerodynamic characteristics of the three plain airfoils are given in figures 4, 5, and 6. These characteristics include those for the three airfoils of

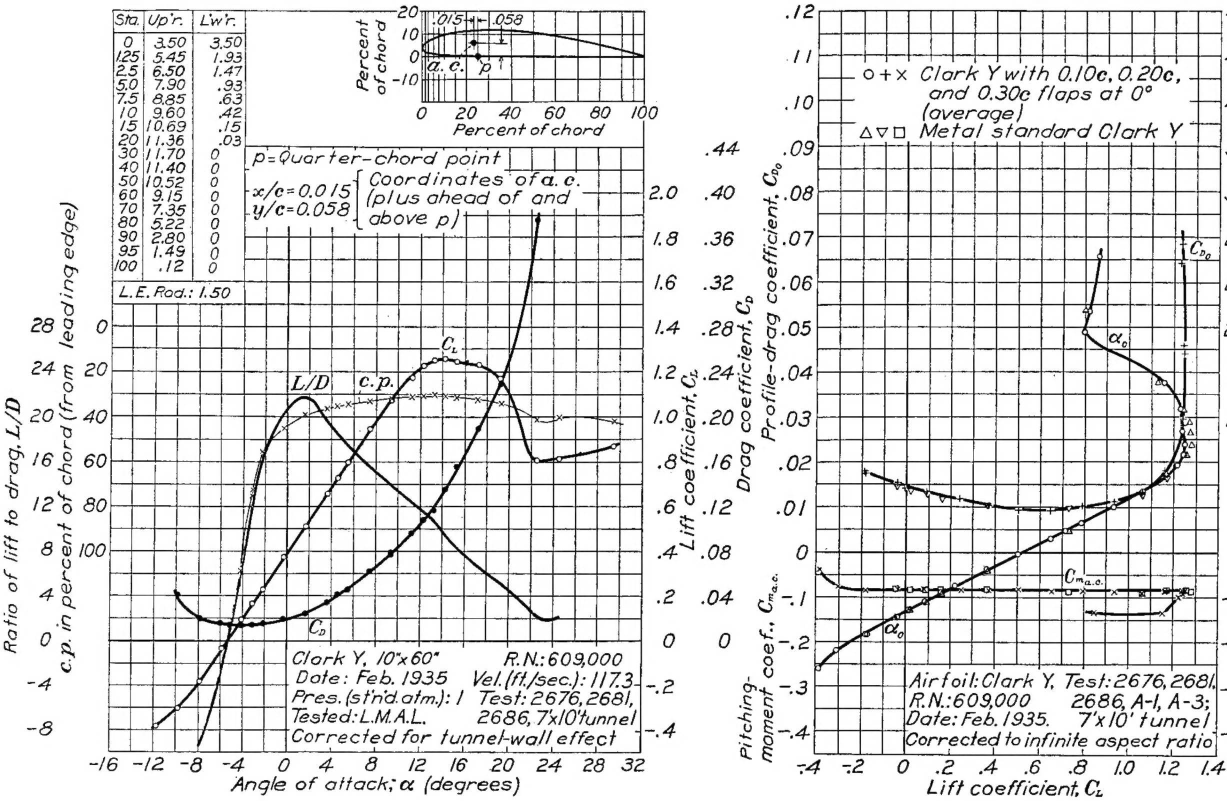

FIGURE 4.—The Clark Y airfoil.

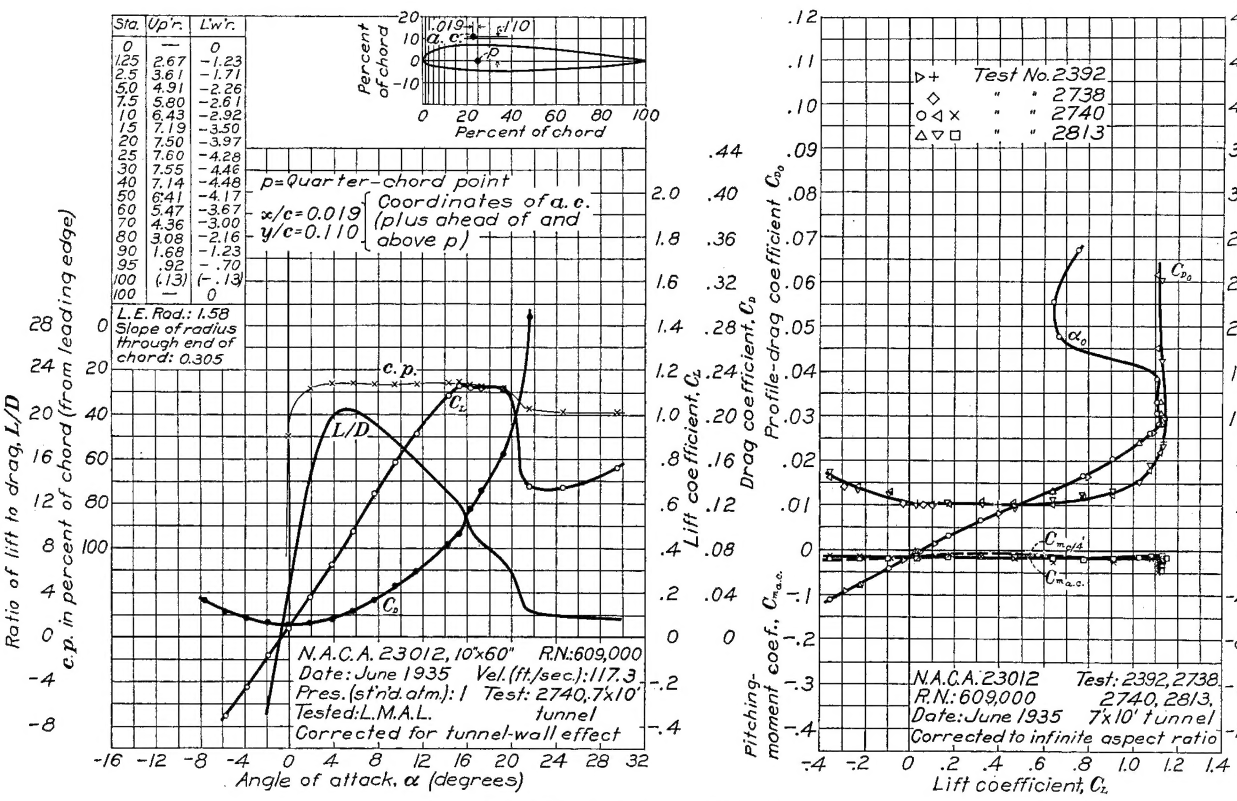

FIGURE 5.—The N. A. C. A. 23012 airfoil.

aspect ratio 6 corrected to free-air conditions, profile-drag coefficients, and angle of attack for infinite aspect ratio.

AIRFOILS WITH FLAPS

Clark Y airfoil with ordinary flap.—Lift, drag, and center-of-pressure characteristics for the airfoil with the 10-percent-chord flap are given in figure 7. These results are for the airfoil with the gap between the flap and main portion of the airfoil completely sealed with plasticine. Values of L/D and $C_{m_{c/4}}'$ for the 10-percent-chord flap are given in figure 8. Values of $C_{L_{max}}$ and values of L/D and C_D at $C_{L_{max}}$ are given in figure 9 for different deflections of the 10-percent-chord flap. The latter characteristics are given for the conditions in which the gap between the flaps and the main portion from references 5 and 6.) The effects on $C_{L_{max}}$ are shown and the effects on L/D and C_D at $C_{L_{max}}$. From these results it may be concluded that split flaps of the same width give somewhat higher maximum lifts than do ordinary flaps. Values of L/D and C_D at $C_{L_{max}}$ are nearly the same for both types of flap. Practically no further gain in maximum lift is obtained by increasing the flap chord beyond 20 percent of the airfoil chord, the data indicating that with wider split flaps the maximum lift remains about the same but that it drops off with wider ordinary flaps. The optimum width of either ordinary or split flaps for maximum lift appears to be 20 percent of the airfoil chord.

Clark Y airfoil with a 20-percent-chord split flap.—For comparison with tests of the N. A. C. A. 23012 and N. A. C. A. 23021 airfoils having split flaps, the

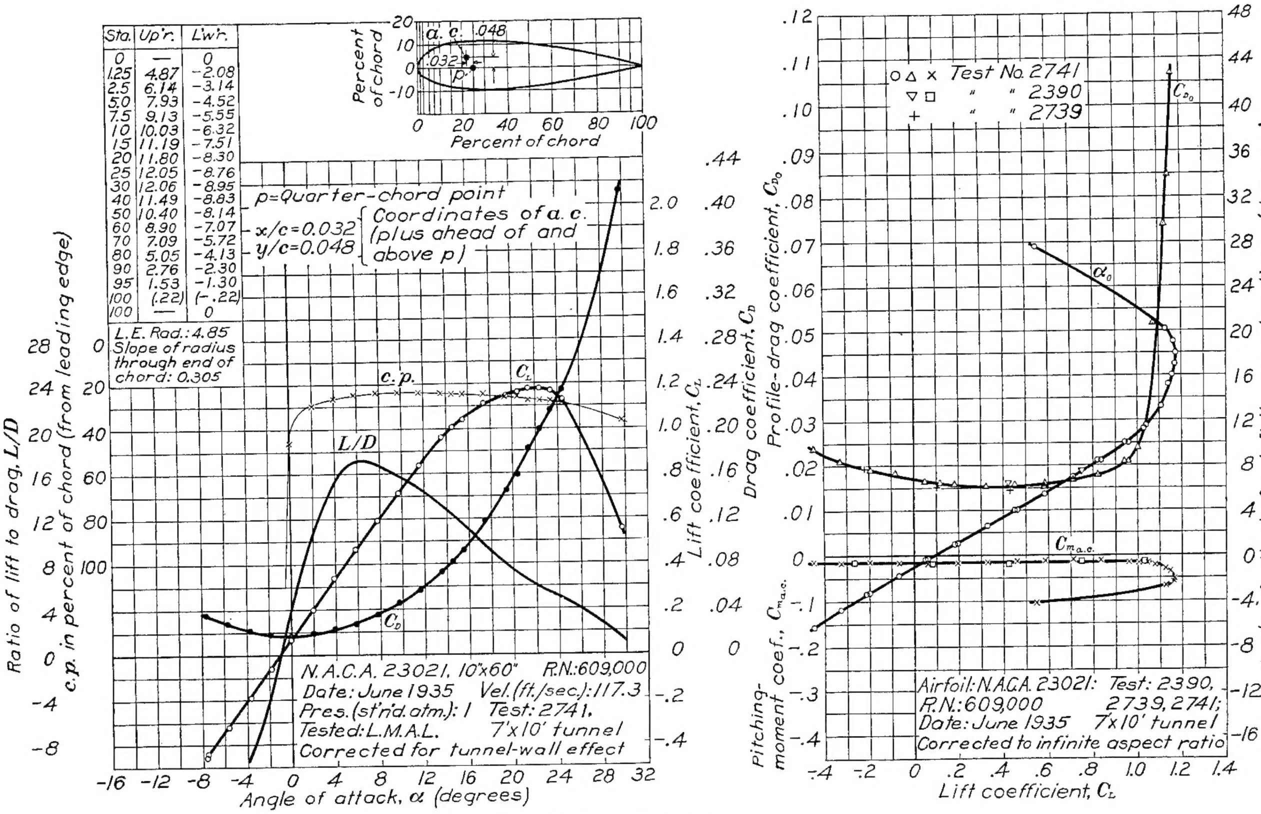

FIGURE 6.—The N. A. C. A. 23021 airfoil.

of the airfoil is both open and sealed. It will be noted from figure 9 that even a small open gap had a very detrimental effect on the maximum lift of the airfoil. It is therefore essential to keep the flap gaps completely sealed to obtain the best characteristics with ordinary flaps. Similar charts for the airfoil with a 20-percent-chord flap are shown in figures 10, 11, and 12. Charts for the airfoil with a 30-percent-chord flap are given in figures 13, 14, and 15.

Optimum sizes of ordinary and split flaps on the Clark Y airfoils.—Figure 18 gives a comparison of different widths of ordinary and of split flaps on Clark Y airfoils. (The data for the split flaps are taken lift, the drag, and the center-of-pressure characteristics for a Clark Y airfoil with a 20-percent-chord split flap are given in figure 16. These data were taken from reference 6 and have been corrected for a wing of aspect ratio 6 in free air. The L/D and $C_{m_{c/4}}'$ for the Clark Y airfoil with split flap are given in figure 17. A comparison of 20-percent-chord ordinary and split flaps on a Clark Y airfoil is given in figure 19. This figure shows the variation of $C_{L_{max}}$ and of L/D and C_D at $C_{L_{max}}$ for different flap deflections. As previously noted, the split flap gives a somewhat higher maximum lift than does the ordinary flap but has slight effect on the other factors.

N. A. C. A. 23012 airfoil with 20-percent-chord ordinary and split flaps.—Lift, drag, and center-of-pressure characteristics are given in figure 20 for a 20-percent-chord ordinary flap on the N. A. C. A. 23012 airfoil. The L/D and $C_{m_{c/4}}'$ for the 20-percent-chord ordinary flap are given in figure 21. Similar curves for 20-percent-chord split flaps are given in figures 22 and 23. A comparison of ordinary and split flaps on the N. A. C. A. 23012 airfoil is given in figure 24. This figure shows the effects of $C_{L_{max}}$ as well as of L/D and C_D at $C_{L_{max}}$ for different flap deflec-

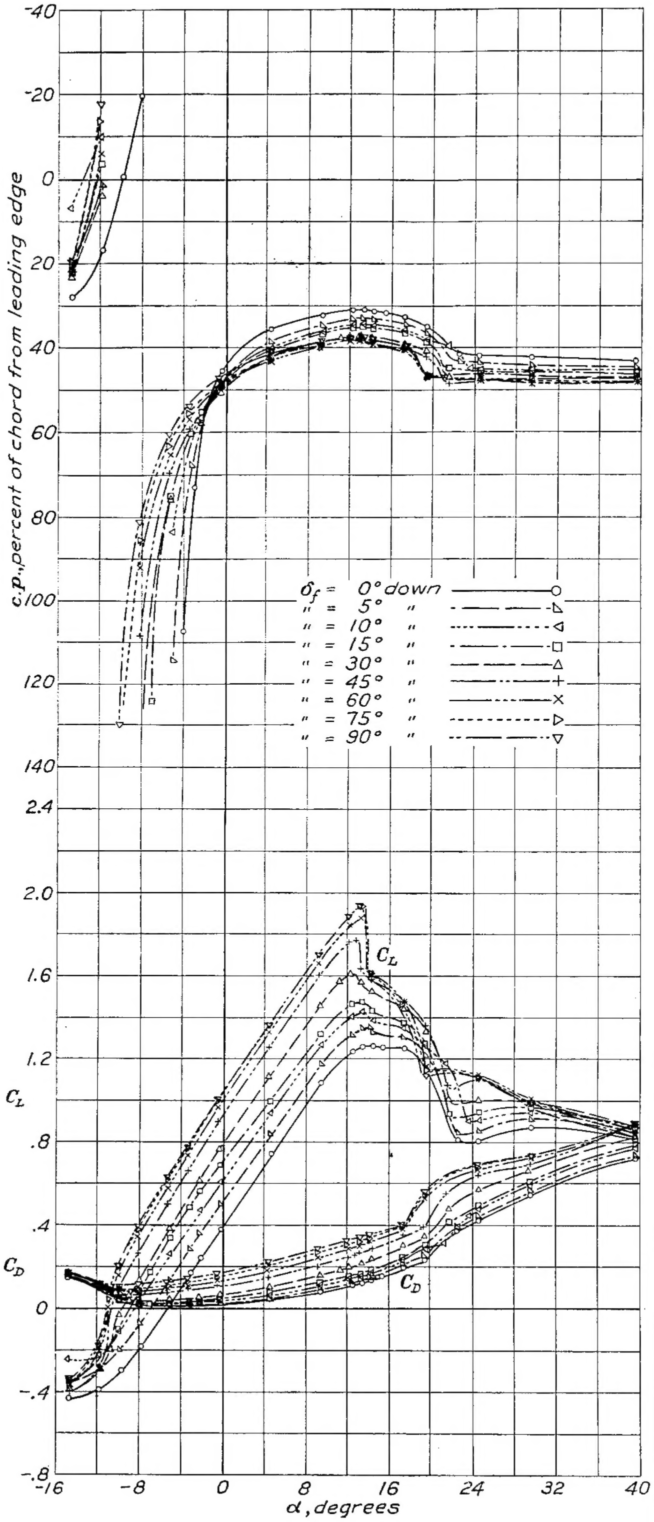

FIGURE 7.—Lift, drag, and center of pressure for the Clark Y airfoil with 0.10c full-span ordinary flap. Flap gap sealed.

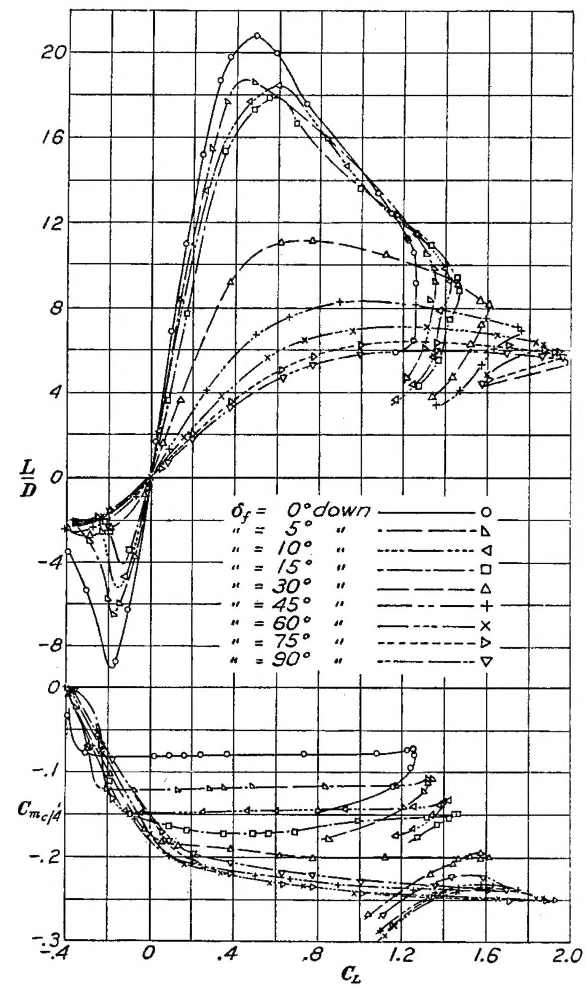

FIGURE 8.—Lift-drag ratio and pitching-moment coefficient for the Clark Y airfoil with 0.10c full-span ordinary flap. Flap gap sealed.

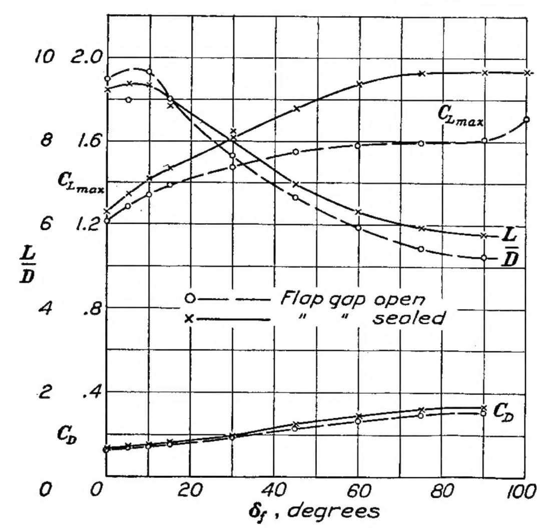

FIGURE 9.—Effect of flap deflection on maximum lift, and on lift-drag ratio and drag at maximum lift. The 0.10c full-span ordinary flap on the Clark Y airfoil.

tions. As in the case of the Clark Y airfoil, the split flap gave a higher maximum lift on the N. A. C. A.

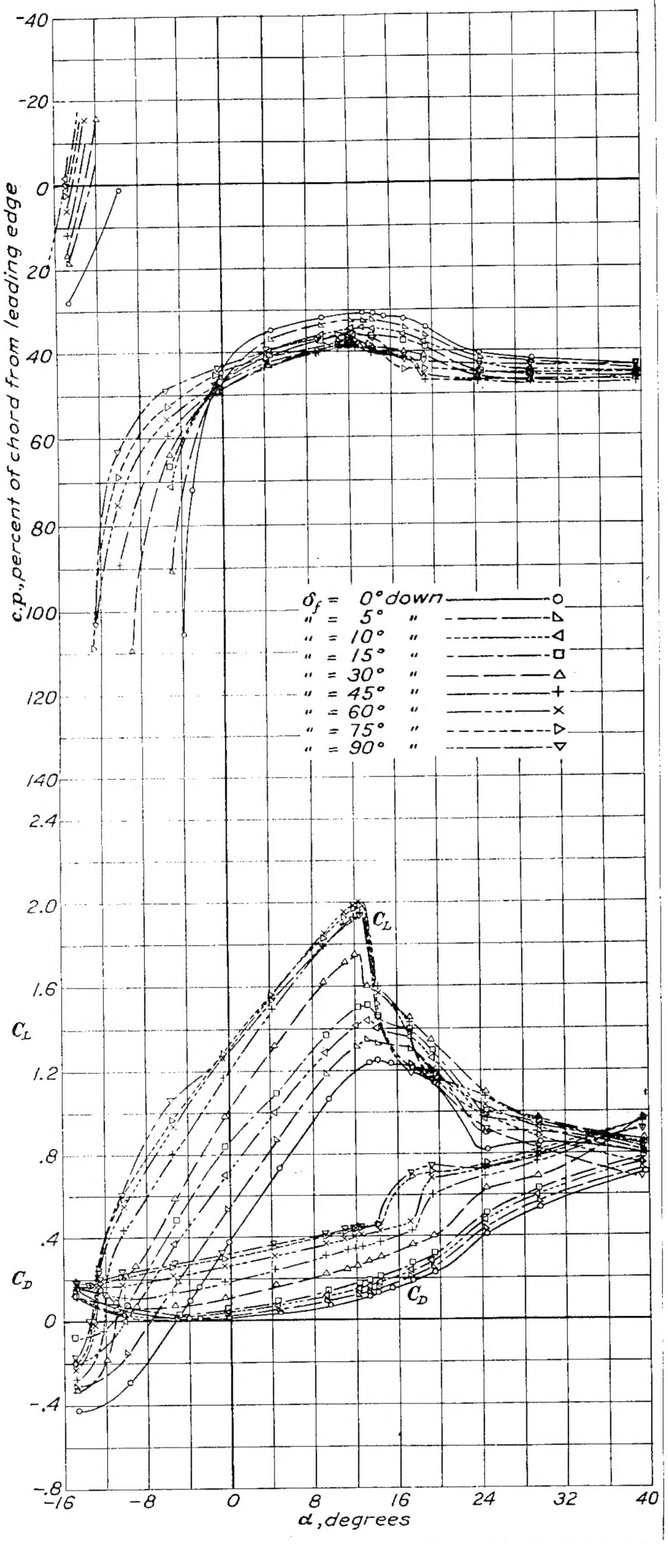

FIGURE 10.—Lift, drag, and center of pressure for the Clark Y airfoil with 0.20c full-span ordinary flap. Flap gap sealed.

23012 airfoil than did the ordinary flap. In addition, the two types of flap had almost the same effect on the other factors considered.

N. A. C. A. 23021 airfoil with 20-percent-chord ordinary and split flaps.—Charts similar to those for

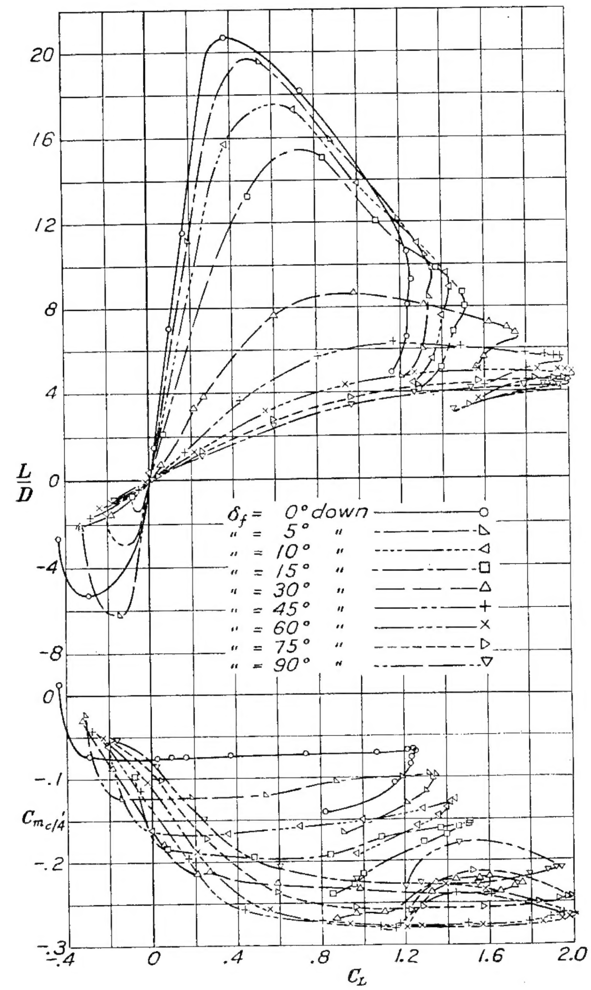

FIGURE 11.—Lift-drag ratio and pitching-moment coefficient for the Clark Y airfoi with 0.20c full-span ordinary flap. Flap gap sealed.

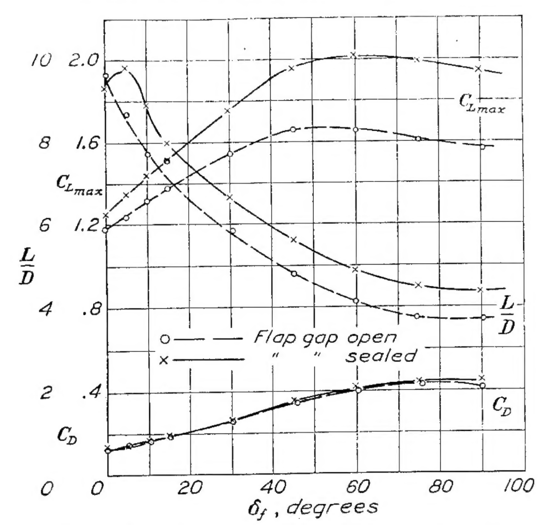

FIGURE 12.—Effect of flap deflection on maximum lift, and on lift-drag ratio and drag at maximum lift. The 0.20c full-span ordinary flap on the Clark Y airfoil.

the N. A. C. A. 23012 airfoil are given for the N. A. C. A. 23021 airfoil with flaps in figures 25, 26, 27, 28,

and 29. The ordinary and split flaps on the N. A. C. A. 23021 airfoil also showed the same relative effects as they did on the Clark Y and on the N. A. C. A. 23012 airfoils.

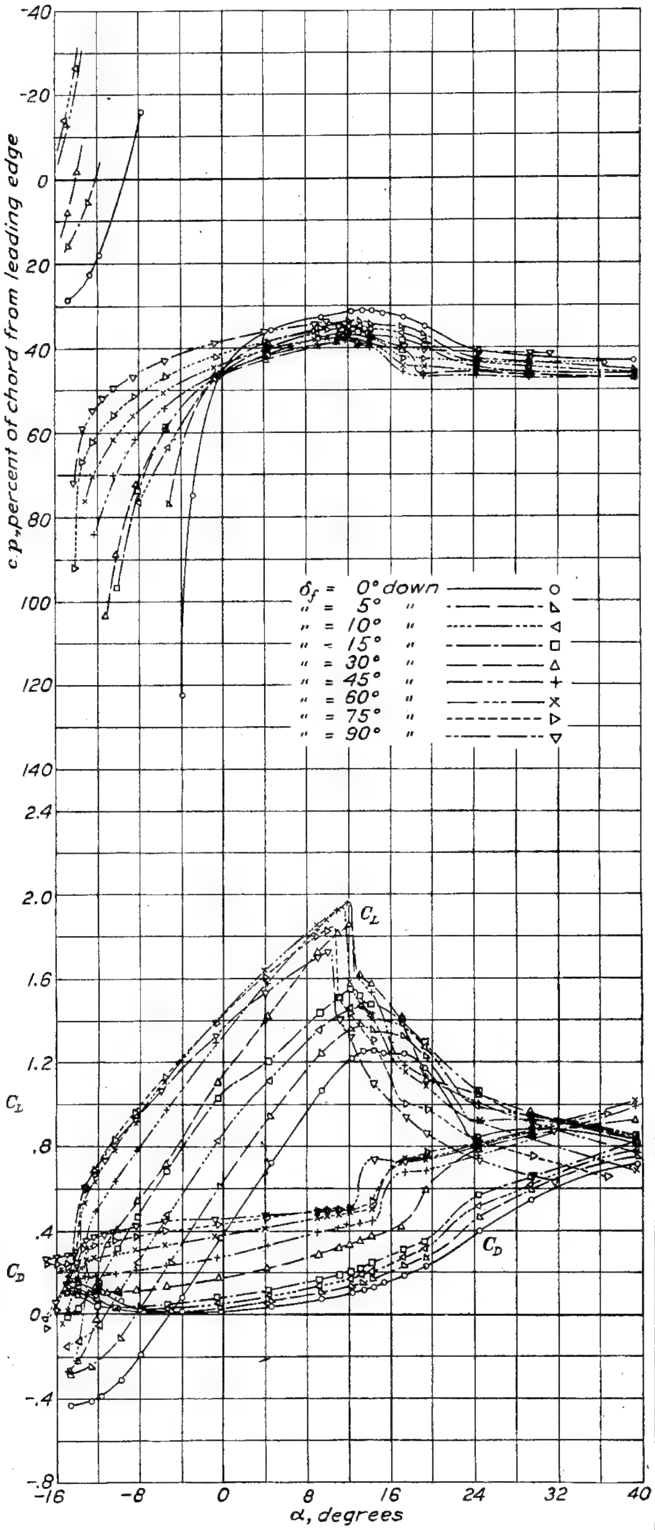

FIGURE 13.—Lift, drag, and center of pressure for the Clark Y airfoil with 0.30c full-span ordinary flap. Flap gap sealed.

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Comparison of lift effects of 20-percent-chord ordinary and split flaps on Clark Y, N. A. C. A. 23012, and N. A. C. A. 23021 airfoils.—Table I shows the effects at a test Reynolds Number of 609,000 on the

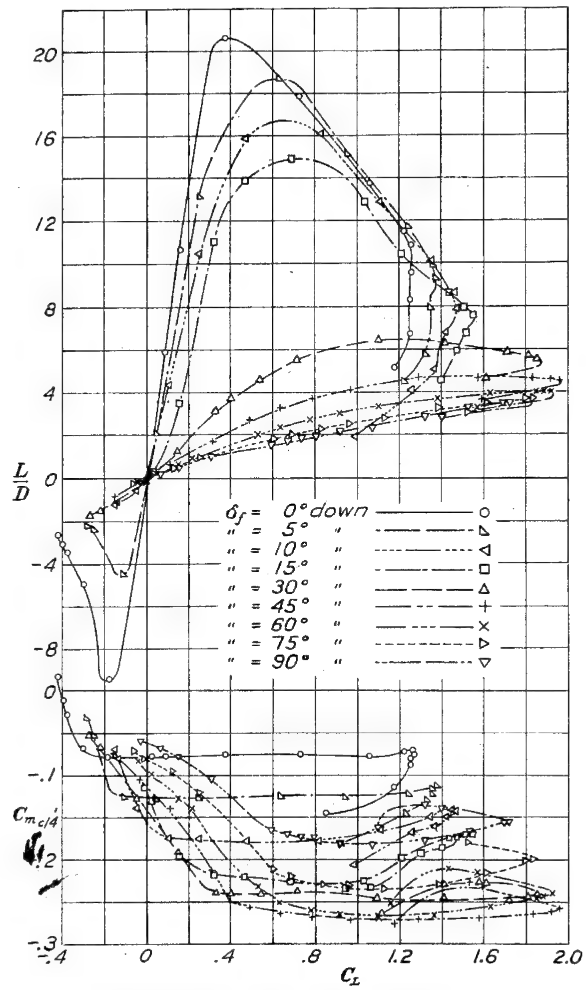


FIGURE 14.—Lift-drag ratio and pitching-moment coefficient for the Clark Y airfoil with 0.30c full-span ordinary flap. Flap gap sealed.

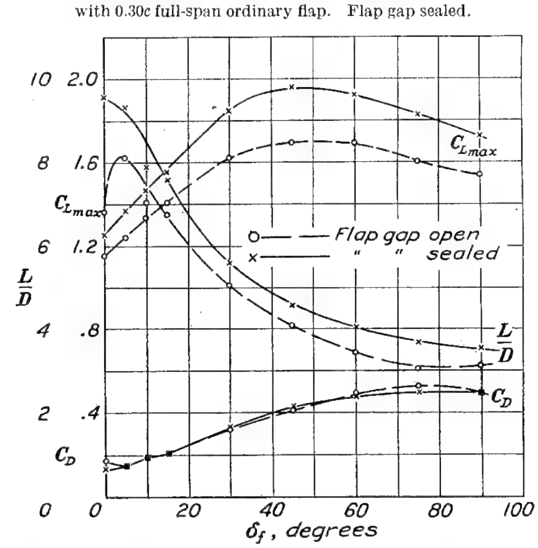


FIGURE 15.—Effect of flap deflection on maximum lift, and on lift-drag ratio and drag at maximum lift. The 0.30c full-span ordinary flap on the Clark Y airfoil.

maximum lift coefficient with flaps neutral; on the maximum lift coefficient with flaps deflected; on the increment in maximum lift coefficient due to the two

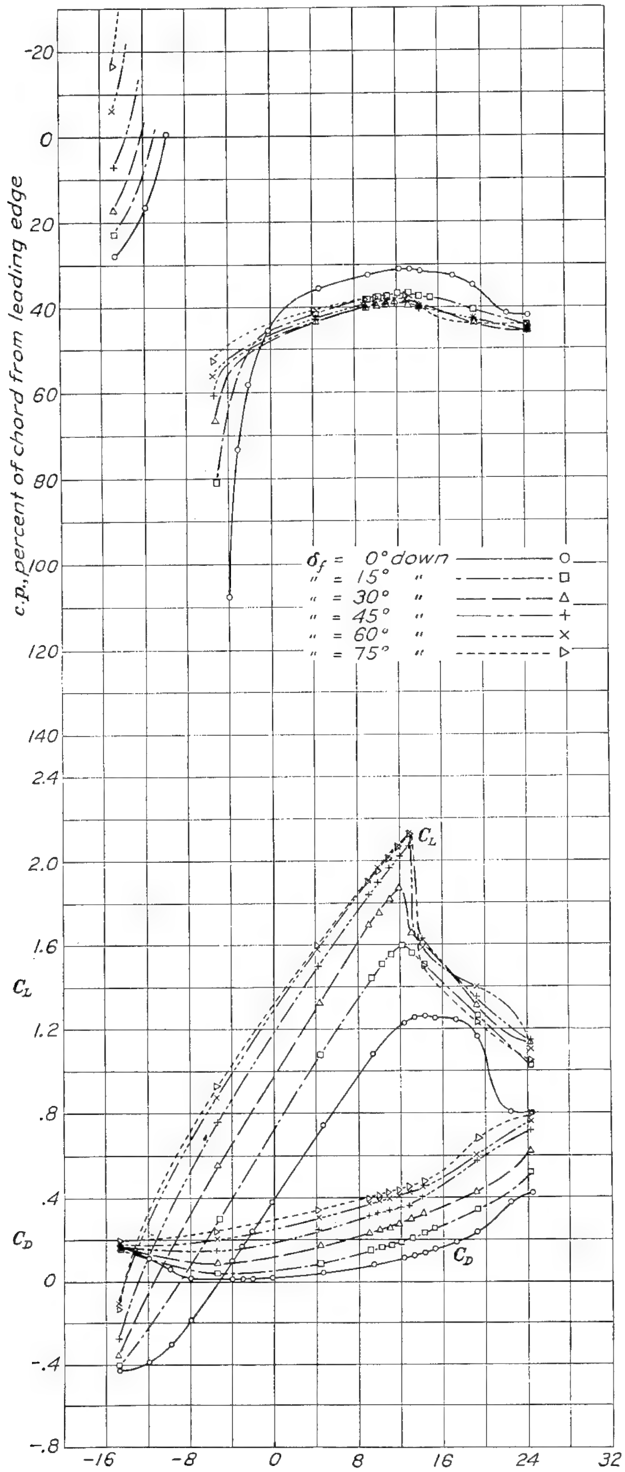


FIGURE 16.—Lift, drag, and center of pressure for Clark Y airfoil with 0.20c full-span split flap. (Data from reference 6.)

types of flaps on various airfoils; on the ratio of maximum lift to minimum drag; and on the ratio of lift to drag at maximum lift.

Somewhat higher maximum lift coefficients and greater increments in maximum lift were given by the

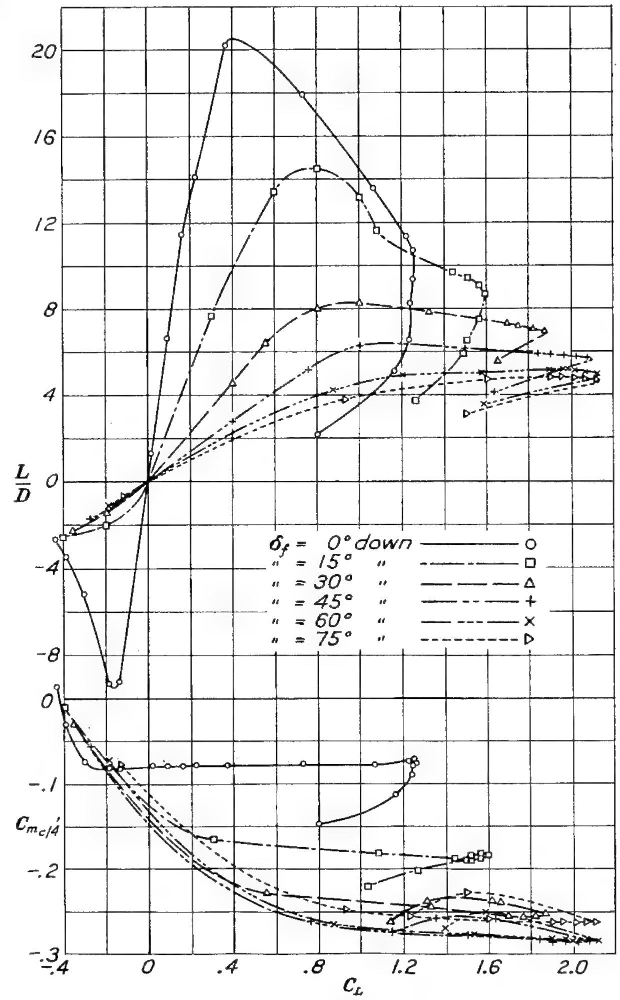


FIGURE 17.—Lift-drag ratio and pitching-moment coefficient for the Clark Y airfoil with 0.20c full-span split flap.

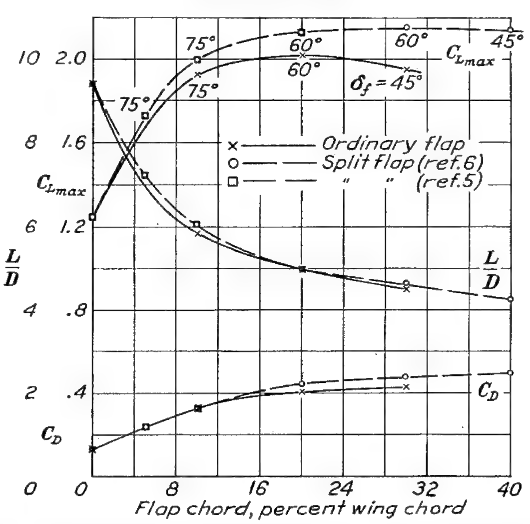


FIGURE 18.—Effect of flap chord on maximum lift, and on lift-drag ratio and drag at maximum lift for both ordinary and split flaps on the Clark Y airfoil.

split flap than by ordinary flaps on the three airfoils tested. The highest maximum lift coefficient and the

greatest increment in maximum lift were both given by flaps on the N. A. C. A. 23021 airfoil. In this case an

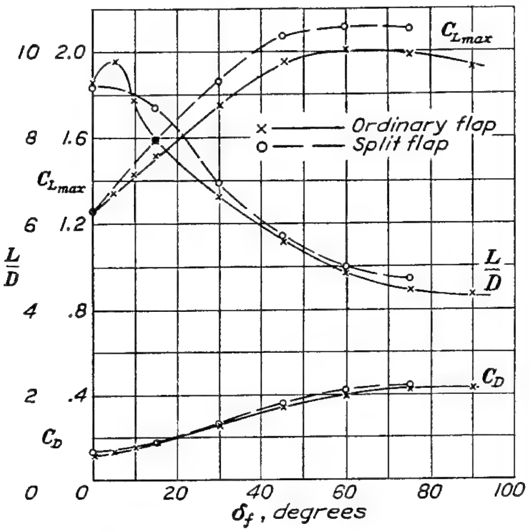


FIGURE 19.—Effect of flap deflection on maximum lift, and on lift-drag ratio and drag at maximum lift. The 0.20c full-span ordinary and split flaps on the Clark Y airfoil.

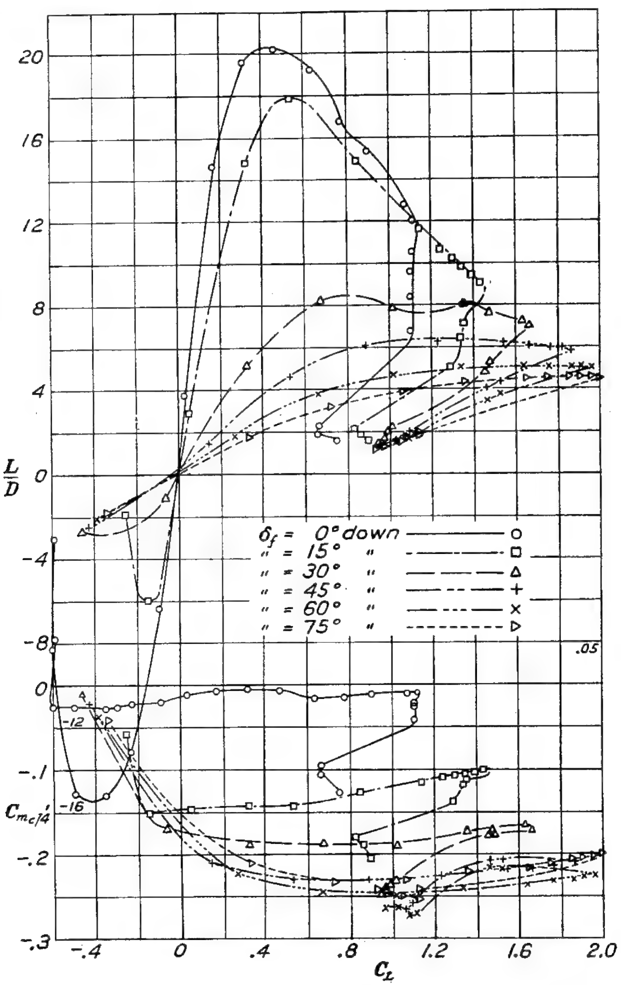


FIGURE 21.—Lift-drag ratio and pitching-moment coefficient for the N. A. C. A. 23012 airfoil with 0.20c full-span ordinary flap. Flap gap sealed.

increment in maximum lift coefficient of 1.193 was obtained, which represents an increase in the maximum lift above that of the plain airfoil of more than 100 percent. The highest speed-range ratio $C_{L_{max}}/C_{D_{min}}$ was given, however, by flaps on the N. A. C. A. 23012 air-

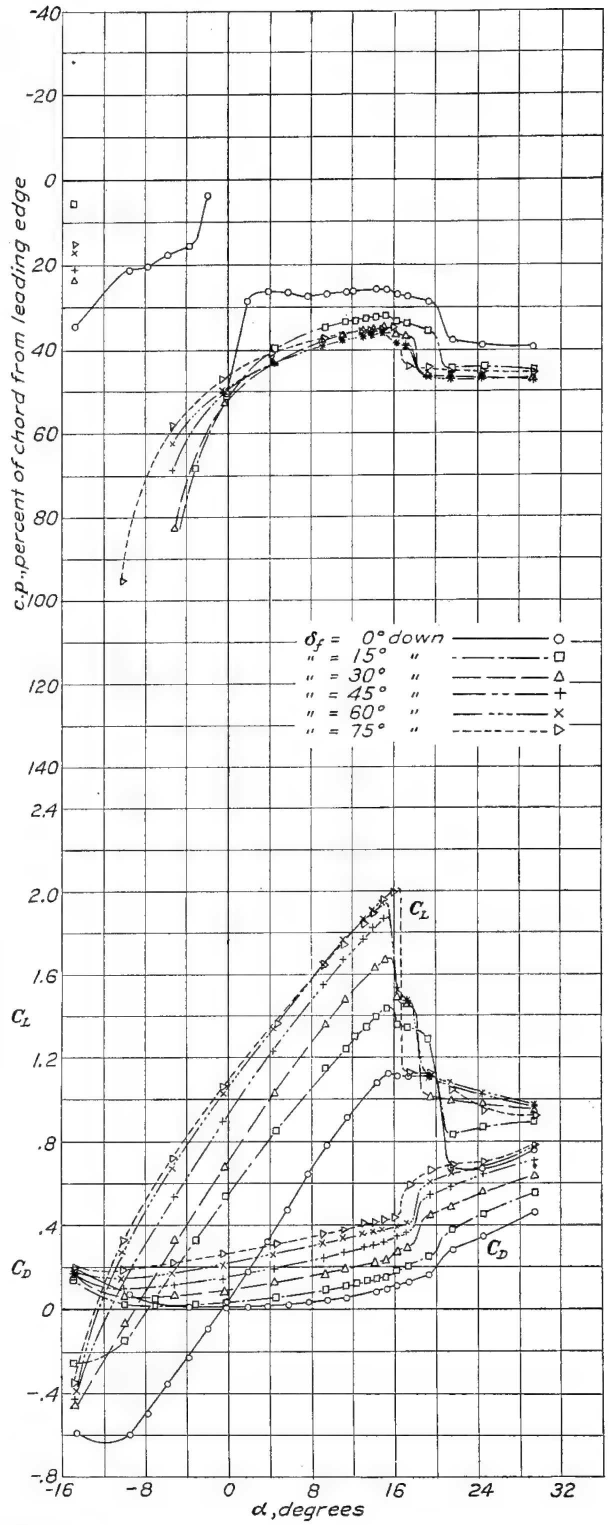


FIGURE 20.—Lift, drag, and center of pressure for the N. A. C. A. 23012 airfoil with 0.20c full-span ordinary flap. Flap gap sealed.

foil, which has a lower maximum lift but which also has a considerably lower minimum drag. The steepest

gliding angle attainable (indicating L/D at $C_{L_{max}}$) is the same with either type of flap on the particular airfoil considered.

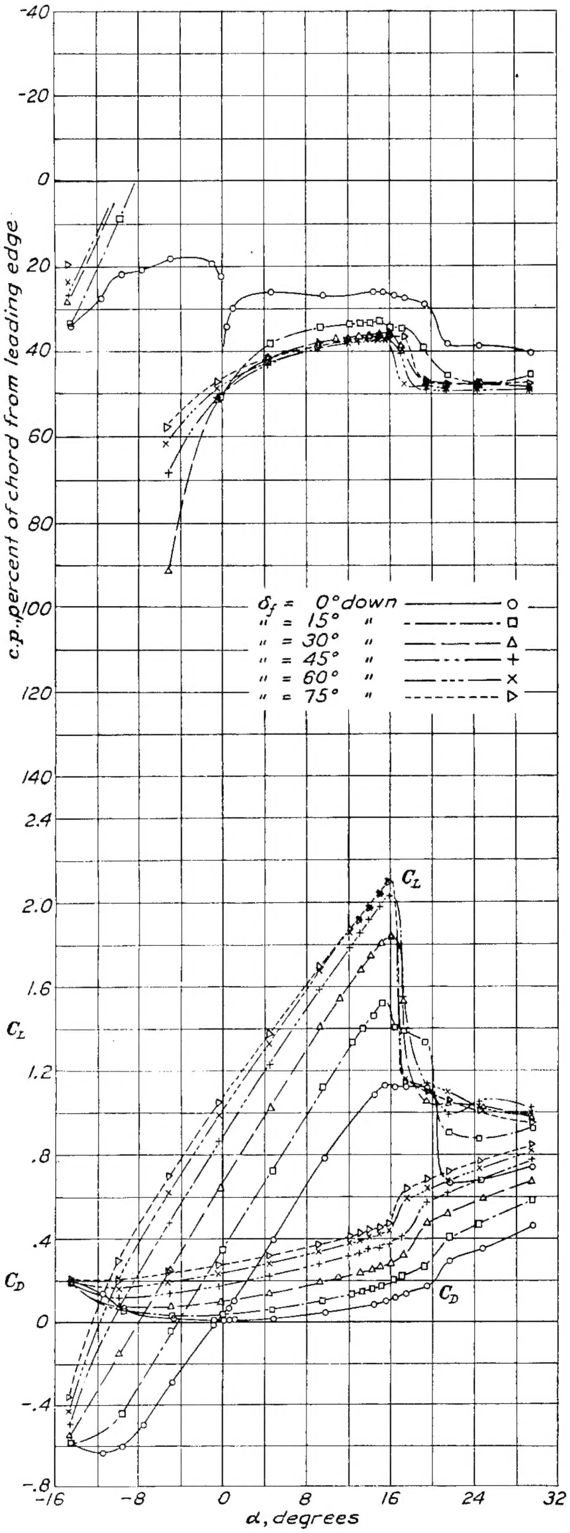


FIGURE 22.—Lift, drag, and center of pressure for the N. A. C. A. 23012 airfoil with 0.20c full-span split flap.

Some tests in the full-scale tunnel and in the variable-density tunnel (reference 7) indicate that the maximum

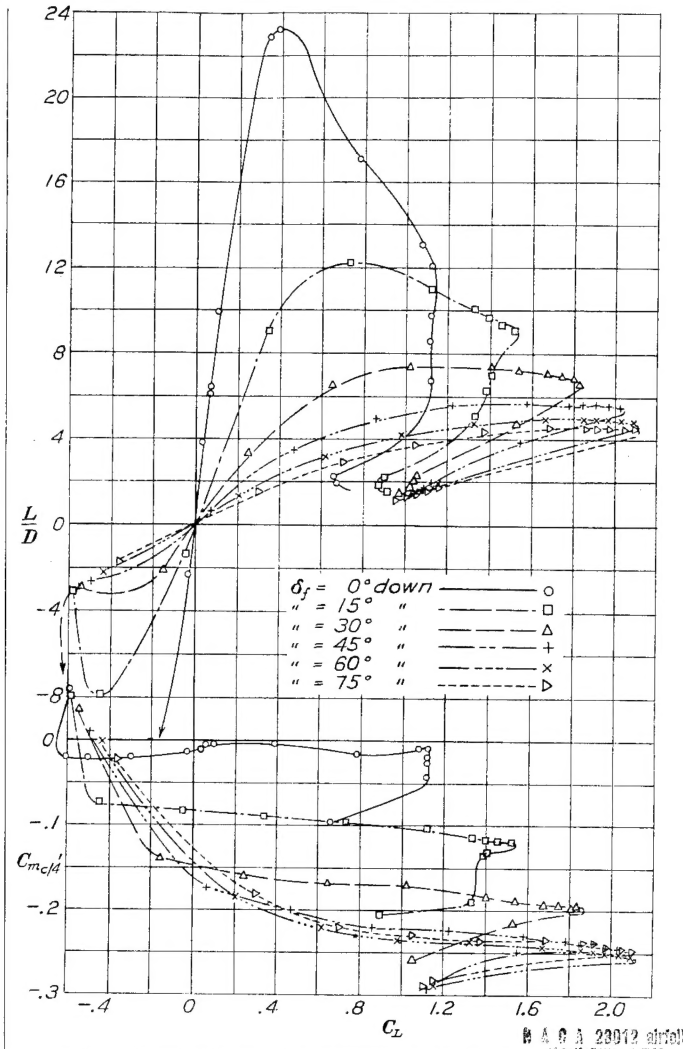


FIGURE 23.—Lift-drag ratio and pitching-moment coefficient for the ~~Clark Y airfoil~~ N A C A 23012 airfoil with 0.20c full-span split flap.

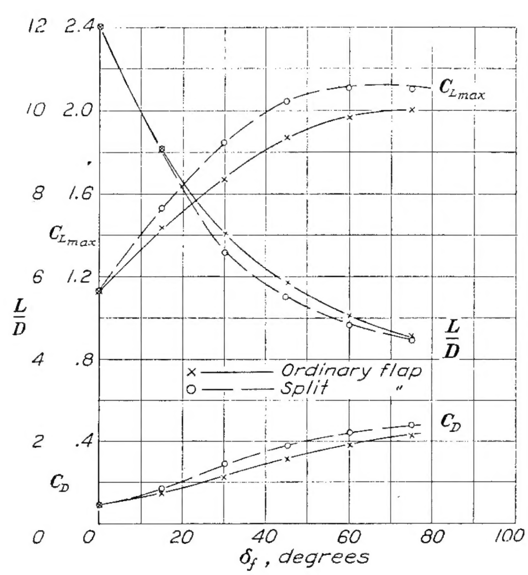


FIGURE 24.—Effect of flap deflection on maximum lift, and on lift-drag ratio and drag at maximum lift. The 0.20c full-span ordinary and split flaps on the N. A. C. A. 23012 airfoil.

lift of the N. A. C. A. 23012 airfoil is equal to or slightly greater than that of the Clark Y airfoil in the normal full-scale range of the Reynolds Number. Further-

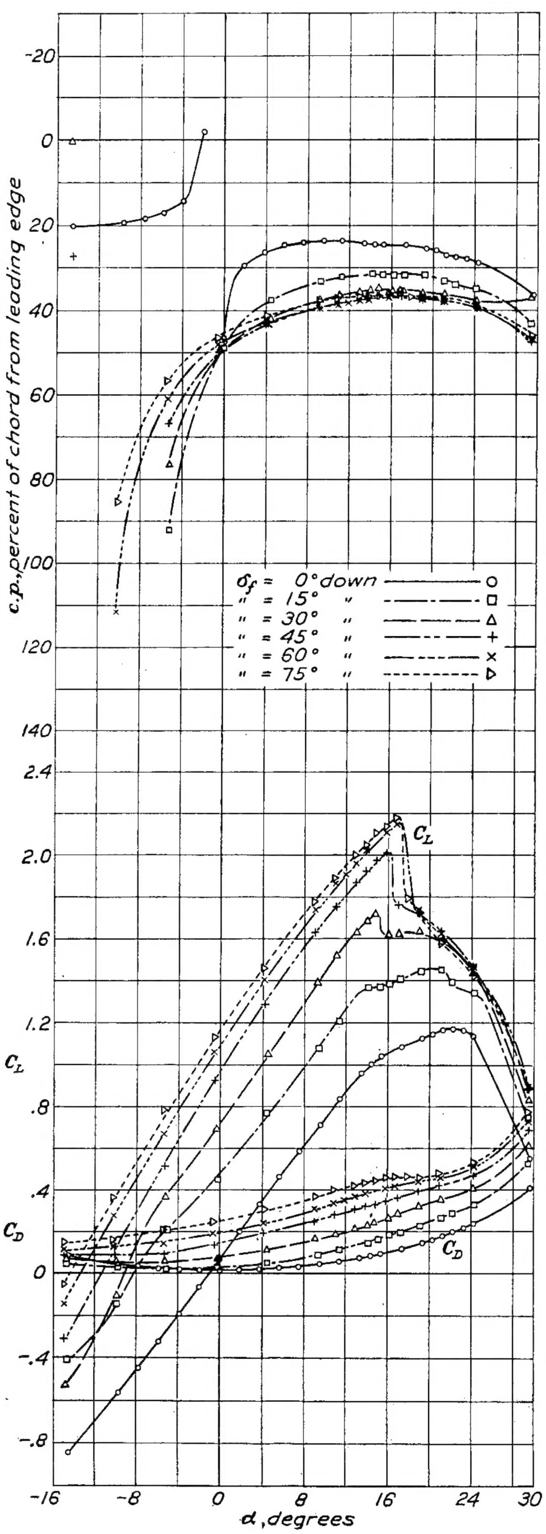


FIGURE 25.—Lift, drag, and center of pressure for the N. A. C. A. 23021 airfoil with 0.20c full-span ordinary flap. Flap gap sealed.

more, recent tests in the variable-density tunnel show that at large as well as at small Reynolds Numbers the N. A. C. A. 23021 airfoil has considerably lower maximum lift than the Clark Y. Thus, it appears that the N. A. C. A. 23012 plain wing will have some ad-

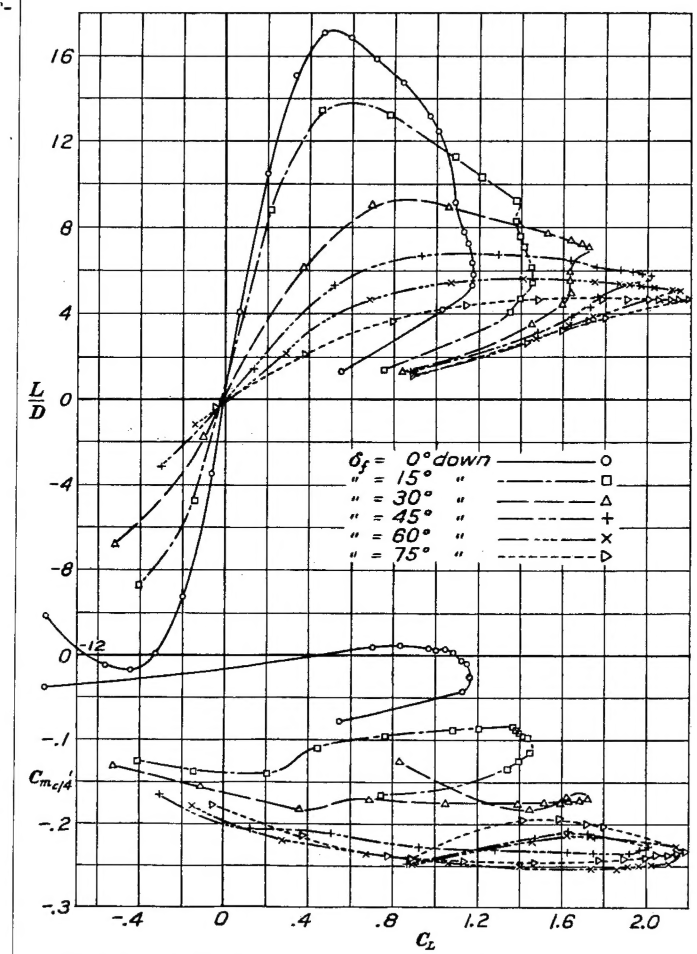


FIGURE 26.—Lift-drag ratio and pitching-moment coefficient for the N. A. C. A. 23021 airfoil with 0.20c full-span ordinary flap. Flap gap sealed.

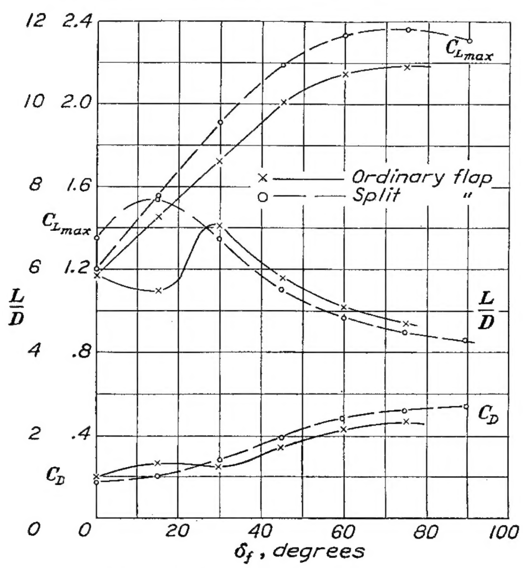


FIGURE 27.—Effect of flap deflection on maximum lift, and on lift-drag ratio and drag at maximum lift. The 0.20c full-span ordinary and split flaps on the N. A. C. A. 23021 airfoil.

vantages over the Clark Y or N. A. C. A. 23021 wings in the full-scale range of the Reynolds Number that

are not shown by low-scale tests if the lift increments due to the flaps are not adversely affected. Experimental data (unpublished) have shown that actually the increments in maximum lift due to split flaps on medium-thick airfoils vary but little with Reynolds Number. In connection with the present investigation, a few tests were made in the variable-density tunnel to determine the scale effect on $C_{L_{max}}$ at high

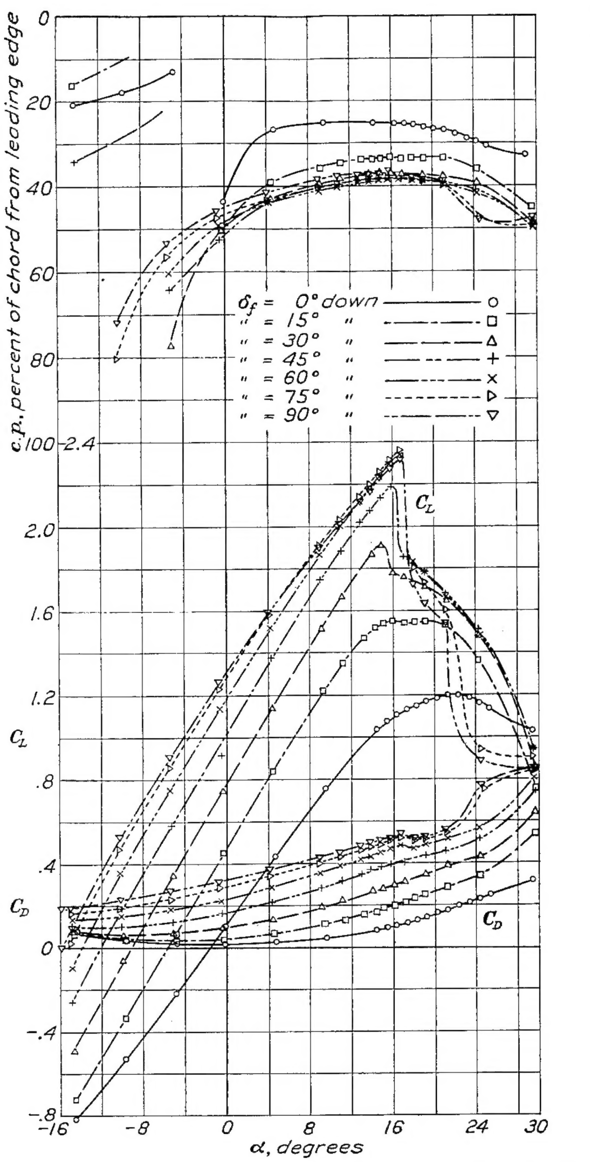


FIGURE 28.—Lift, drag, and center of pressure for the N. A. C. A. 23021 airfoil with 0.20cf ull-span split flap.

Reynolds Numbers of the N. A. C. A. 23021 airfoil (a thick section) with a 20-percent-chord split flap. The results of the scale-effect tests are given in figure 30 in which $C_{L_{max}}$ for the N. A. C. A. 23021 airfoil with the flap neutral and with the flap deflected downward 75° is plotted against "effective" Reynolds Number both for the 7- by 10-foot and the variable-density wind tunnels.

(Effective Reynolds Number = test R $\times \frac{\text{critical R free air}}{\text{critical R tunnel}}$. See reference 7.) The value of the factor is 1.4 for the 7- by 10-foot wind tunnel and 2.6 for the variable-density wind tunnel. The data show that the scale effect is about the same for the N. A. C. A. 23021 airfoil with the flap deflected downward 75° as it is for

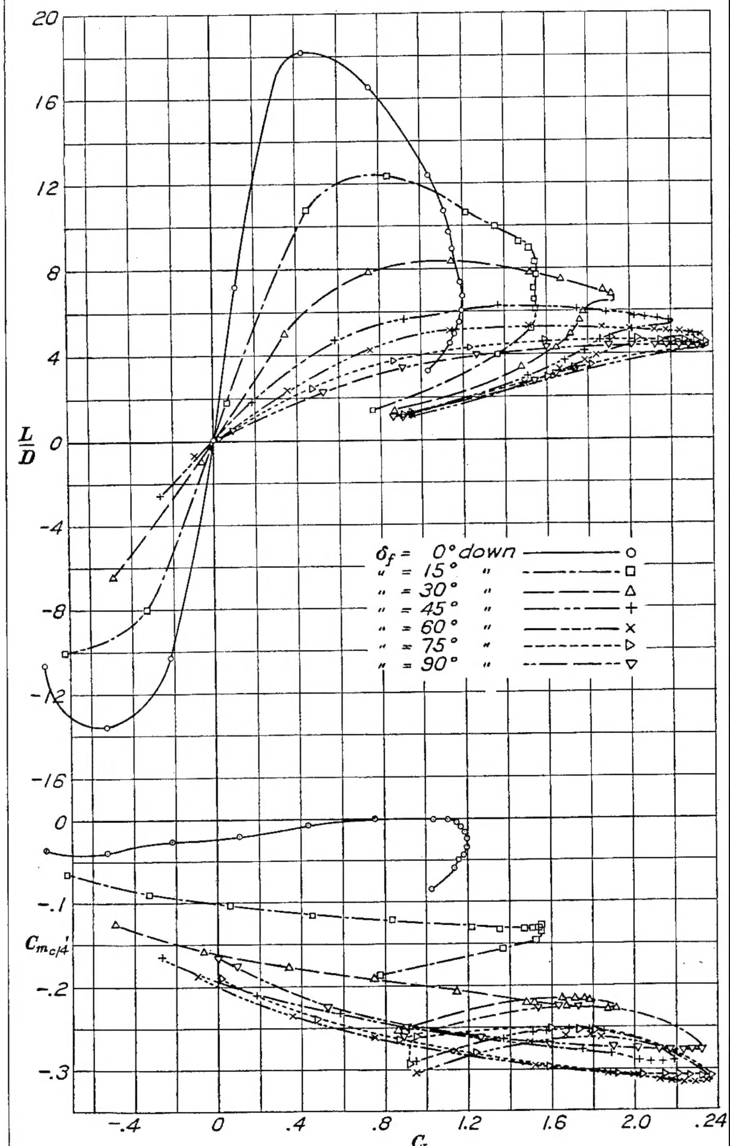
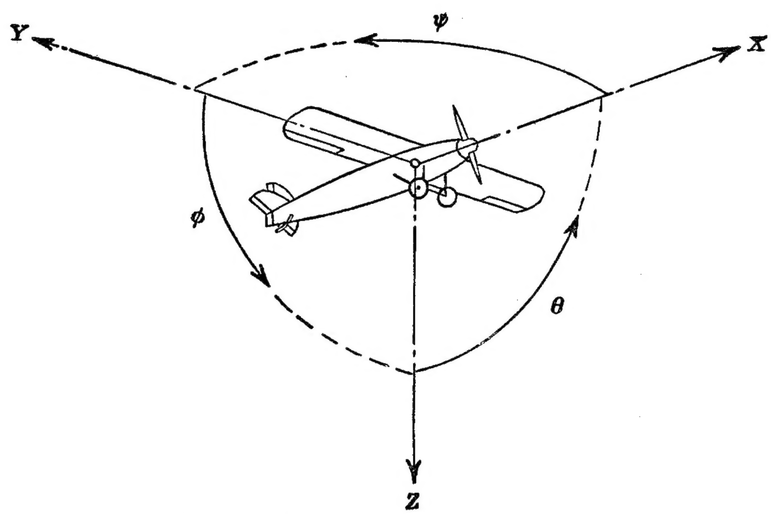


FIGURE 29.—Lift-drag ratio and pitching-moment coefficient for the N. A. C. A. 23021 airfoil with 0.20c full-span split flap.

the plain airfoil and that the increment in $C_{L_{max}}$ due to the deflected split flap is, therefore, practically independent of scale effect. It seems fairly well established that increments of $C_{L_{max}}$ due to split flaps on medium-thick and thick airfoils are independent of scale effect, so that values of the increments obtained at the relatively low scale of the present tests may be directly applied to full-scale wings.



Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	$Y \longrightarrow Z$	Roll	ϕ	u	p
Lateral	Y	Y	Pitching	M	$Z \longrightarrow X$	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	$X \longrightarrow Y$	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l=\frac{L}{qbS}$ (rolling) $\quad C_m=\frac{M}{qcS}$ (pitching) $\quad C_n=\frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$
C_s, Speed-power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$
η, Efficiency
n, Revolutions per second, r.p.s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 hp. = 76.04 kg-m/s = 550 ft-lb./sec.
1 metric horsepower = 1.0132 hp.
1 m.p.h. = 0.4470 m.p.s.
1 m.p.s. = 2.2369 m.p.h
1 lb. = 0.4536 kg.
1 kg = 2.2046 lb.
1 mi. = 1,609.35 m = 5,280 ft.
1 m = 3.2808 ft.